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Policy review of greenhouse gas emission reduction in Taiwan

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ABSTRACT

In 2008, Taiwan government passed a set of rules designed to achieve a sizable reduction of carbon dioxide (CO_2) emissions, namely, "Frameworks of Sustainable Energy Policy". The target of the policy is to keep CO_2 emissions during the 2016–2020 periods at the 2008 level, to reduce them to the 2000 level in 2025, and to cut that level in half by 2050. Currently, the acts of "Statute for Renewable Energy Development" and "Energy Management Act (amendment)" is being implemented while those of "Greenhouse Gas (GHG) Reduction Act (draft)" and "Regulation for Energy Tax (draft)" is being scheduled for legislative reviewing. These acts deal with GHG emission reduction via various policy instruments such as cap and trade, subsidies, and taxes. The present paper presents a detailed review of the policy progress of GHG emission reduction in Taiwan in addition to the assessment of the outcome of GHG emission reduction in the past decade. It also proposed the priority of policy implementation of GHG emission reduction in the country in the post-Kyoto era.

Contents

1. Introduction

As Kyoto Protocol came into effect in February 2005, nations around the world have been involved in extensive discussions and disputes over implementation of the Kyoto mechanisms of United Nations Framework Convention on Climate Change (UNFCCC), including the responsibilities, obligations and collaborations pertinent to greenhouse gas (GHG) emission reduction and climate change adaptation, as well as post-Kyoto control framework. Taiwan is not one of the signatories of Kyoto Protocol, so currently it does not have to undertake any duty in GHG emission reduction. Even though, Taiwan has a strong willingness to participate in global actions to reduce GHG emissions and to fulfill its responsibilities as a member of the global village. In addition, since Taiwan's economy is export-oriented, it is very likely to be directly or indirectly subjected to international regulation on GHG

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emission reduction through the influence of the global industrial supply chain. Moreover, the tendency toward high-priced energy requires effective coordination and integration of energy and environmental policies. Therefore, the Executive Yuan (Cabinet) of Taiwan passed the "Frameworks of Sustainable Energy Policy – an Energy-Saving and Carbon-Reduction Action Plan" in 2008, which aims to considerably reduce carbon dioxide (CO_2) emissions in Taiwan. The target of the plan is to keep carbon dioxide emissions during the 2016–2020 periods at the 2008 level, to reduce them to the 2000 level in 2025, and to cut that level in half by 2050. The government is now speeding up its formulation of measures to help lower GHG emissions, such as developing renewable energy, improving energy efficiency, imposing carbon tax on fossil fuels, and increasing low-carbon energy in the power structure. The objective of this paper is to assess the outcome of GHG emission reduction of Taiwan in the past decade. Then, an updated review of the policy progress of GHG emission reduction is presented. It also proposes integration planning strategies of the policy instruments related to energy and GHG reduction in the country in the post-Kyoto era.

2. Energy supply structure

Taiwan, with land area of 36,190 km^2 and population of 22.86 millions, has the world's second highest population density, i.e. 621 capita per km^2. During the last 20 years (1988–2008), with the exception of negative growth of gross domestic product (GDP) in 2001 (−2.17%), Taiwan's annual GDP growth rates ranged from 1.7% to 12.6% [1]. In order to maintain the momentum of economic growth, Taiwan relies on vast energy supply. In the meantime, the average annual growth rate for total installed power capacity is 3.1%, while average annual growth rate for peak load is 1.0%. It is obvious that rapid economic progress is followed by higher energy demand during the last two decades in this country. That is GDP and energy consumption are highly correlated in Taiwan's economy.

However, Taiwan is lack of indigenous energy and more than 98.1% of total energy supply is imported. Fig. 1 shows the structure variation by fuels of total primary energy supply (TPES) of Taiwan from 1990 to 2007 [2]. The total amount of primary energy supply increased from 40.5 million metric tons of oil equivalent (TOE) in 1990 to 112.56 million metric tons of oil equivalent in 2007, for an annual average growth rate of 5.1%. From 1990 to 2007, the structure of energy supply by fuel in Taiwan has changed as follows:

- Coal's share increased from 23.6% in 1990 to 37.6% in 2007,
- Petroleum decreased from 54.3% to 42.7%,
- Natural gas increased from 3.2% to 9.8%,
- Hydropower decreased from 1.13% to 0.34%,
- Nuclear power decreased from 17.7% to 9.36%, and
- Renewable energy (hydropower exclusive) increased 0.04% to 0.12%.

Basically, Taiwan is highly dependent on fossil fuels (such as coal, petroleum, and natural gas) in its energy mix, with these energy forms together accounting for 90.1% of total primary energy supply in 2007. Carbon-free fuels (hydropower, nuclear power and renewable energy) however contributed less than 10% of total primary energy supply in 2007.

Fig. 2 further shows the share structures of the total primary energy supply by sectors in Taiwan [2]. From 1990 to 2007, the sectoral share of the total primary energy supply in Taiwan has changed as follows:

- Energy sector share decreases from 9.8% in 1990 to 8.7% in 2007,
- Industrial sector increased from 48.5% to 51.7%,
- Transportation sector decreased from 15.8% to 13.1%,
- Agricultural sector decreased from 2.9% to 0.9%,
- Service sector increased from 6.1% to 10.1%,
- Residential sector changes slightly from 11.9% to 11.2%, and
- Non-energy use sector decreased from 5.1% to 4.3%.

It is clear seen from Fig. 2 that the industry is the largest energy-consumption sector in Taiwan, which uses up more than 50% total primary energy supply in 2007. The agricultural sector reduced its energy use, while the service sector consumed more energy, which

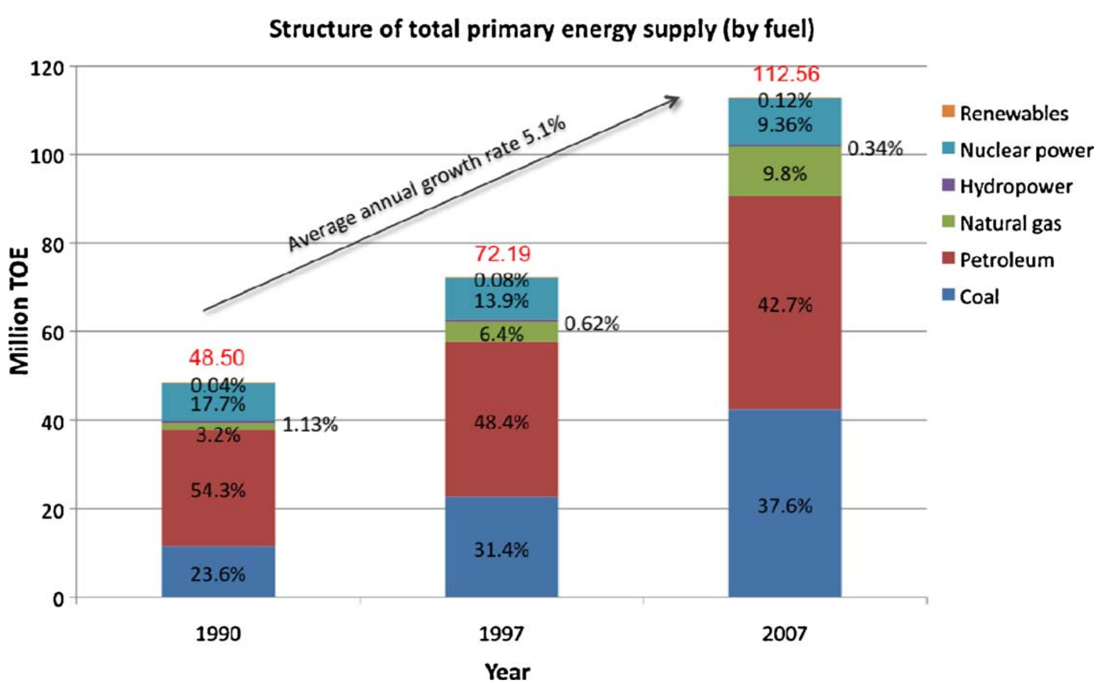


Fig. 1. Structure of total primary energy supply (TPES) by fuel of Taiwan.

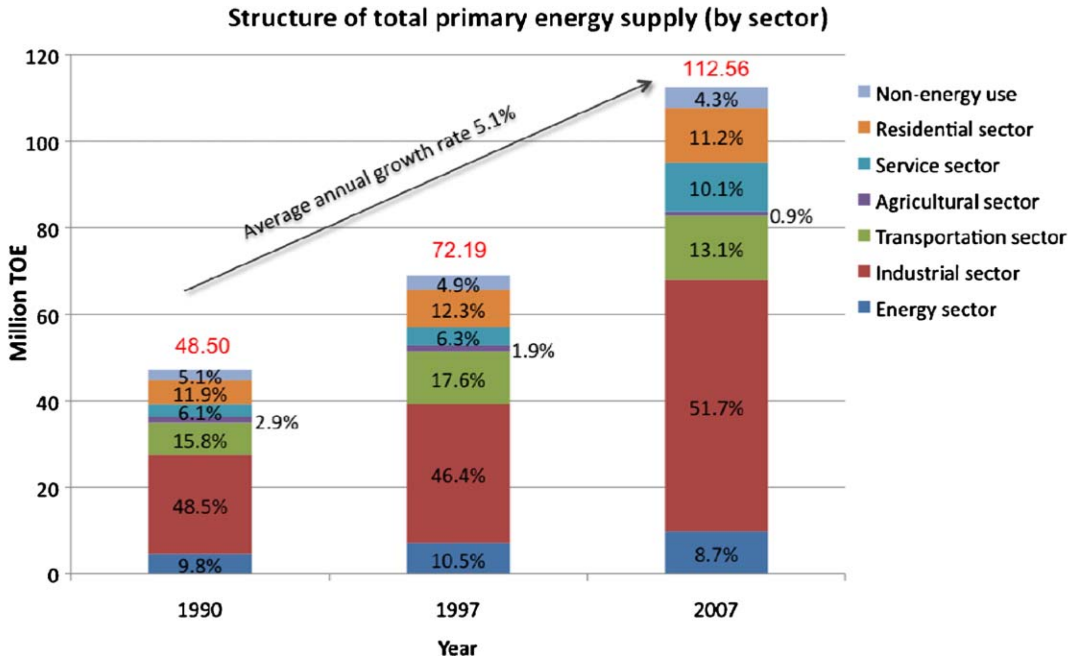


Fig. 2. Structure of total primary energy supply (TPES) by sector of Taiwan.

parallels with the transition of Taiwan's economic structure in passed two decades.

3. Greenhouse gas emission situation

3.1. GHG reduction targets

As shown in Table 1, there are several official proposals of CO_2 reduction target drafted by the Taiwan government since 1998. After the adoption of the Kyoto Protocol in 1997, the Taiwan government drafted a top-down GHG reduction target in "The First National Energy Conference" in 1998. As shown in Fig. 3, the government would reduce CO_2 emissions from fuel combustion to 2000 levels before 2020 (green dashed line). The major reduction strategy was the expansion of nuclear power generation capacity. However with the announcement of the policy of "Nuclear-Free Homeland" in 2001 and the continuing growth of GHG emissions, this target was under serious challenge and review.

Subsequently, in response to the entry into force of the Kyoto Protocol, Taiwan held "The Second National Energy Conference" in 2005 to review the results of past emission reduction efforts and discuss energy use and strategic measures for GHG emission reduction. For the purpose of evaluating the carbon dioxide emission scenario for the energy sector, the Bureau of Energy, the Ministry of Economic Affairs (MOEA) proposed the BAU scenario of Taiwan's carbon dioxide emissions, which will reach 531 million metric tons in 2025, and 616 million metric tons in 2030. The assumptions adopted in the BAU scenario were list in Table 2 [3,4]. Although, the Conference did not reach any consensus on the fixed targets (Kyoto model), the government then proposed a bottom-up target, which is to reduce the emissions in 2025–2030 by 30% below the BAU scenario (center line). At this stage, the expansion of nuclear power generation has been ruled out [5], and the policies of renewable energy promotion, energy efficiency improvement and energy pricing adjustment were adopted instead. The GHG emission reduction strategies of various government agencies in Taiwan are mainly based on the conclusions of The Second National Energy Conference. These strategies can be largely summarized as follows:

- The energy agency needs to actively promote a CO_2 emission control mechanism and regulate major energy investment proposals.
- The industrial agency needs to aggressively help the industries with capacity building, encouraging them to reach voluntary reduction agreements, raising the efficiency standard of the equipment and assisting the industries with production technology enhancement. Thereafter, in June 2006, the government formed Taiwan Industrial Greenhouse Gas Office (TIGO) to govern implementation of the strategy for GHG emission reduction of local industrial sectors.
- The transportation agency needs to develop green transportation, alleviate use and growth of motor vehicles and motorcycles and upgrade energy use efficiency of the transportation system in order to promote "Development of Sustainable Transportation and Pursuit of a Healthy Taiwan."
- The residential and commercial agency needs to commit itself to establishing an incentive mechanism that motivates energy

Table 1
Greenhouse gas reduction target transition.

Year	Policy	Targets	Approach	Governing authority
1998	The First National Energy Conference	Reduce CO_2 emissions from fuel combustion to the 2000 level before 2020	Top down	KMT
2005	The Second National Energy Conference	Reduce CO_2 emissions in 2025–2030 by 30% below the BAU scenario	Bottom up	DDP
2008	Frameworks of Sustainable Energy Policy	Near term: Reduce CO_2 emissions to the 2008 level between 2016 and 2020	Top down	KMT
2009	The Third National Energy Conference	Mid-term: Reduce CO_2 emissions to the 2000 level in 2025		
		Long-term: Cut 50% off based on the 2000 level by 2050		

KMT: Kuomintang (Nationalist Party); DPP: Democracy Progress Party.

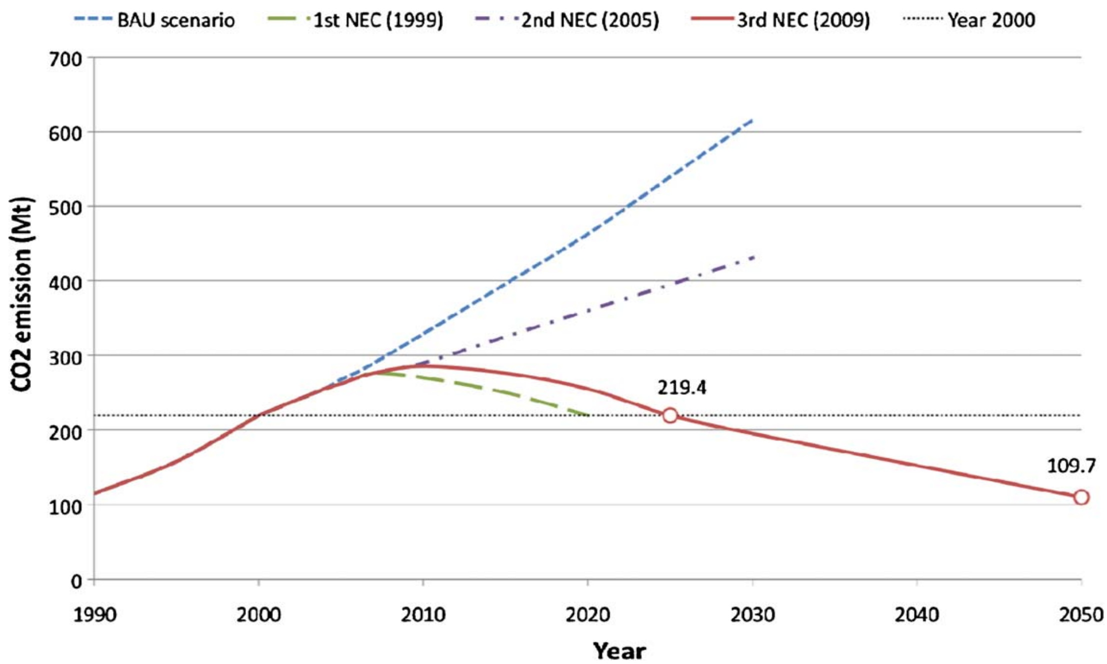


Fig. 3. Targets of CO_2 emission reduction in Taiwan.

conservation, promoting old building energy efficiency improvement service and expanding the green building endeavor.

The above strategies were mostly made from the bottom-up perspective. However, these measures involving changes of human habits and ways of life are very difficult to evaluate their reduction effectiveness. It was found that there is high uncertainty in achieving this GHG reduction target, due to lack of policy evaluation and cost analysis.

In 2008, Taiwan government proposed a set of rules designed to achieve a sizable reduction of carbon dioxide emissions, namely, Frameworks of Sustainable Energy Policy. The target of top-down approach is to keep carbon dioxide emissions during the 2016–2020 periods at the 2008 level, to reduce them to the 2000 level in 2025, and to cut that level in half by 2050. Subsequently, "The Third National Energy Conference" held in 2009 further confirmed these targets.

3.2. GHG emission inventory

The results of CO_2 emission from fuel combustion of Taiwan [6] are evaluated in Figs. 4–8. Fig. 4 shows the trends of total CO_2 emission from 1990 to 2007 in Taiwan. The blue circles are the results using the reference approach (top-down), while the red bars represent the results using the sectroal approach (bottom-up). The annul growth rates of total CO_2 emissions from 1990 to 2000 are about 6.9% and 6.7% for the reference and sectoral approaches, respectively. After 2000, the annul growth rates are reduced to 3.3% for both approaches.

Figs. 5 and 6 show the Taiwan's ranks of total CO_2 emission and per capita CO_2 emission from fuel combustion in the world in 2007, respectively. The results are based on the sectoral approach. It ranks 21st and 18th in the world in total CO_2 emission and per capita CO_2 emission, respectively [6].

Fig. 7 further shows a comparison of change rate of the total CO_2 emission from 1990 to 2007 among several counties and regions. In is seen the total CO_2 emission in 2007 increased 140.8% as compared to the 1990 results, which is much higher than those of the world (38%) and Annex 1 Parties (2.6%). In addition, Taiwan's increase rate of total CO_2 emission is higher than most of the neighboring countries except for China.

Fig. 8 shows the trends of carbon intensity (CO_2 emission/GDP) from 1990 to 2007 for several relevant countries. Except for Korea, Taiwan's carbon intensity is higher than those of countries shown in this figure. In addition, the countries belonging to Annex 1 Parties (Japan, German, UK, France) decrease their carbon intensity after 1995. However, the carbon intensity of Taiwan begins decreasing since 2003. The delay of the decrease in the carbon intensity reflects the waver of governmental ambition in combating the climate change.

3.3. Dilemma of GHG emission reduction

Judging from the above discussion about CO_2 emission from fuel combustion, it is undoubted that Taiwan is not good in the mitigation of climate change in the past two decades, which pushed Taiwan's emissions close to the top 20 among global economies. There are some dilemmas in reduction of GHG emission in Taiwan, which are described below.

First, there is lack of specific national reduction blueprint before 2008. From 1998 to 2008, Taiwan wavered between top-down and bottom-up reduction target, which is a reflection of the national

Table 2
Assumption parameters and CO_2 emissions in BAU scenario.

Items	2000	2010	2020	2030	Annual growth rate (%)		
					2000–2010	2100–2020	2020–2030
GDP (1991 trillion NT$)	88.8	131.8	194.3	272.6	4.84	4.74	4.02
Population (million)	22.3	23.2	23.6	23.3	0.4	0.17	−0.01
CO_2 emission (million tons)	221	329	463	616	48.86	40.72	33.05

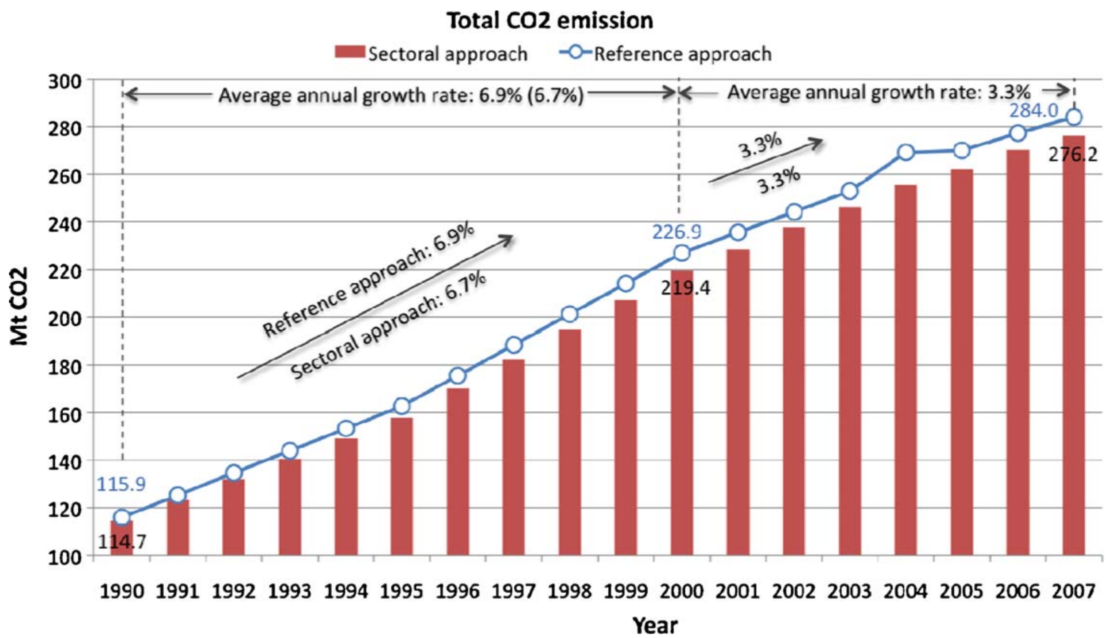


Fig. 4. Trend of total CO_2 emission from 1990 to 2007 in Taiwan.

attitude toward the climate change issues. The ambiguity of international convention caused the uncertainty in government decision-making, and has thus influenced the global community for more than a decade. With the slow progress of the post-Kyoto negotiations like COP13 in Bali and COP15 in Copenhagen, this trend is expected to continue and will subject Taiwan as well as other developing countries (or non-Annex 1 Parties) to more dilemmas in pursuing GHG reductions. In the past decade, there were heated debates over whether Taiwan should establish a goal for GHG emission reduction, and whether the fixed goal (Kyoto model) or the dynamic goal (intensity model) should be adopted for goal attainment. There have been proposals to formulate the goal for GHG emission reduction. But equally loud were the arguments that Taiwan should not jump on any specific goal at the cost of economic growth. The fact that Taiwan lacks specific and feasible overall national positioning and blueprint regarding its GHG emission reduction goal and trade-off between GHG emission reduction policy and economic growth has prevented the reduction strategy from being effective and from significant progress.

Secondly, since the legal provisions for GHG emission reduction, "GHG Reduction Act (draft)," remain in the legislative phase, measures for carrying out GHG emission reduction often meet

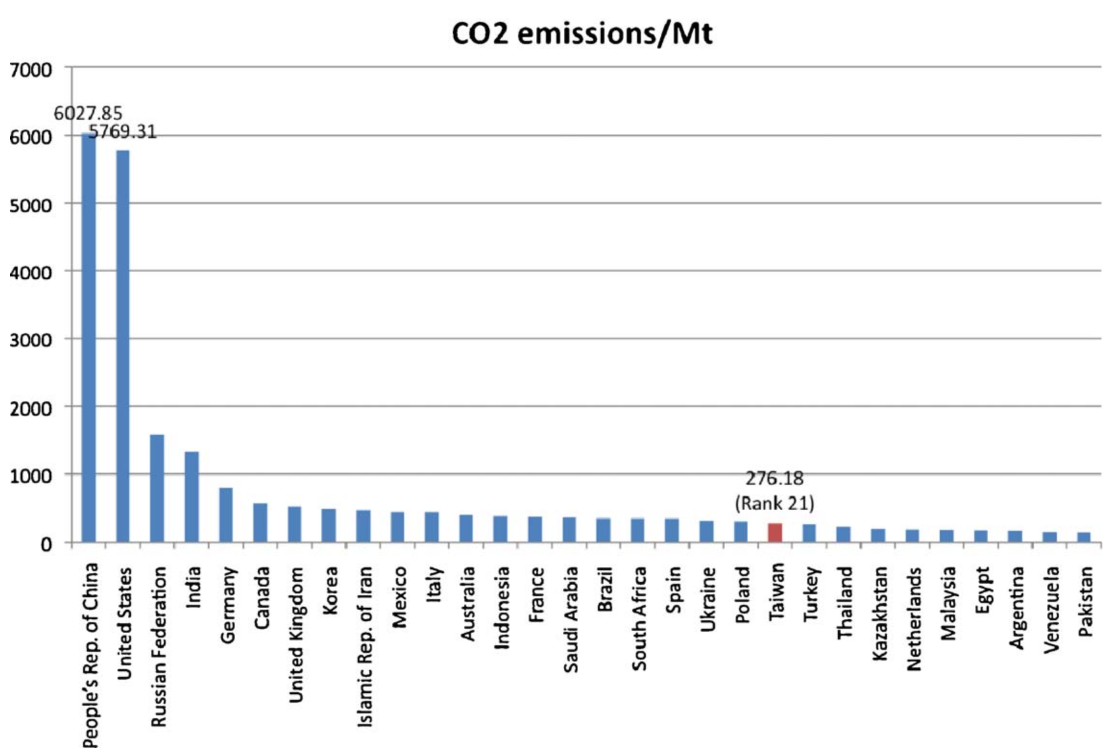


Fig. 5. Taiwan's rank of total CO_2 emission in the world in 2007.

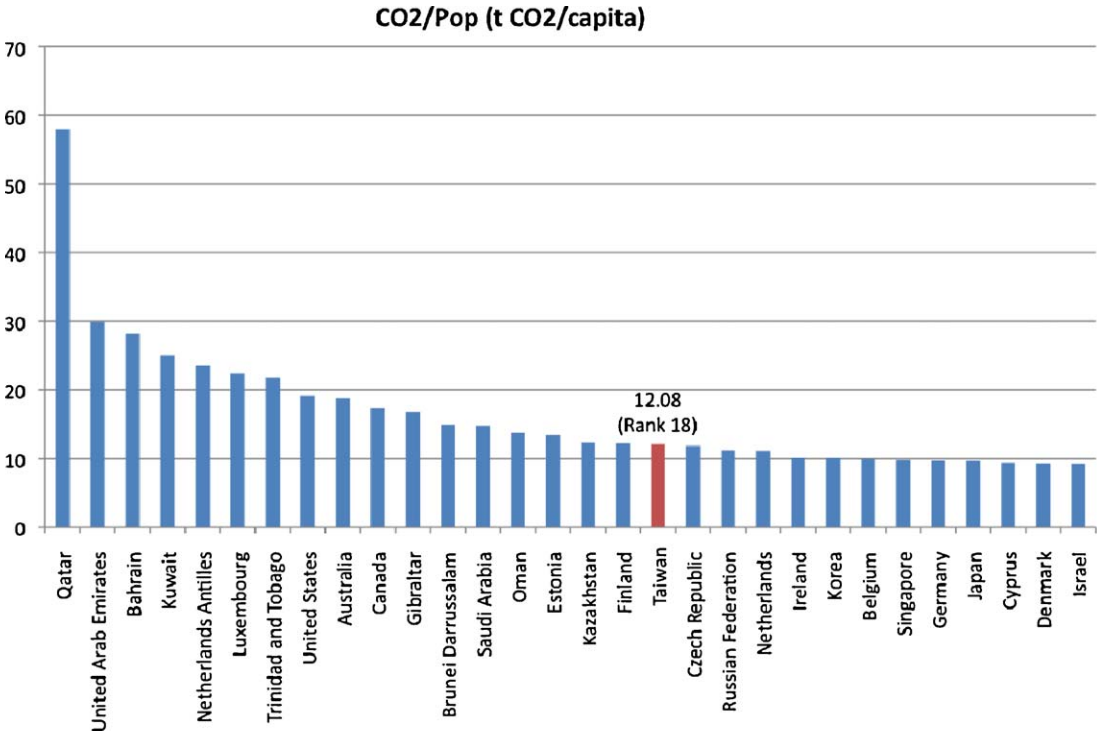


Fig. 6. Taiwan's rank of per capita emission in the world in 2007.

resistance for lack of legal basis. For example, due to the absence of legal basis for enforcement, current implementation projects such as GHG inventory, registration and verification, and voluntary reduction agreement project can only involve voluntary participation. That is the government has no legal authorities to inventory and subsequently cap the GHG emission for all aspects, such as clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry.

Thirdly, the tools of GHG emission reduction are limited. Owing to its unique political position and economic status, Taiwan is unable to take part in the three flexible mechanisms of UNFCCC, i.e., Joint Implementation (JI), Clean Development Mechanism (CDM) and Emission Trade (ET) and as a result cannot carry out GHG emission reduction in a cost-effective manner via international outsourcing. In addition, the limited economic scale is not appealing enough to attract leading companies to invest clean technology and capital in Taiwan.

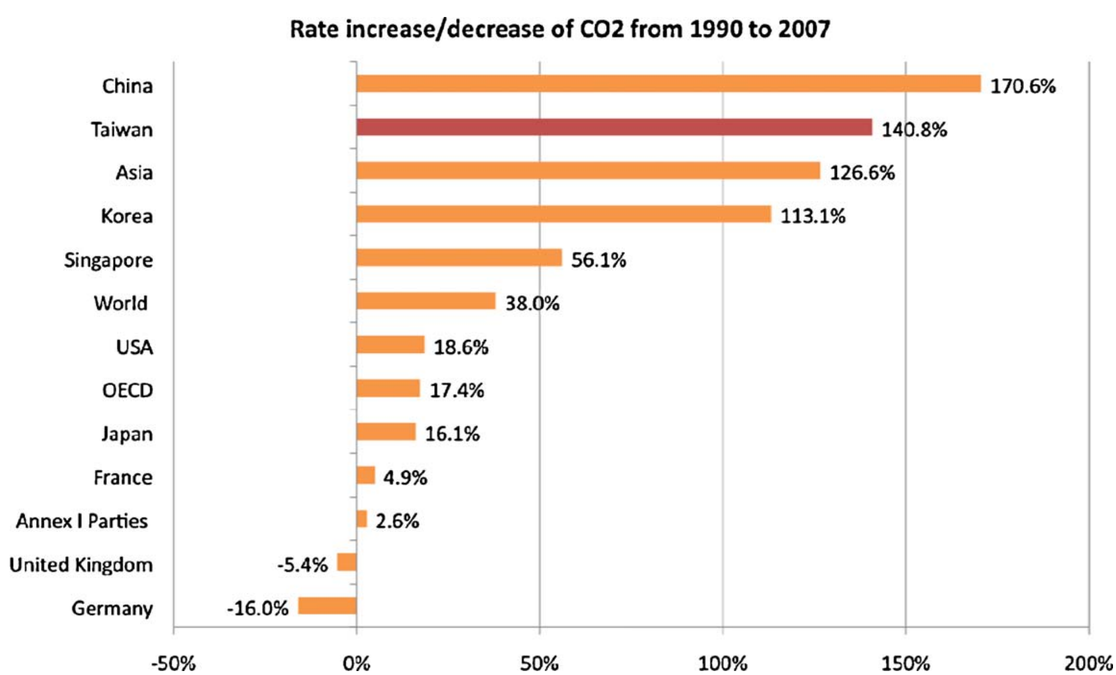


Fig. 7. Comparison of increase/decrease rates of total CO_2 emission from 1990 to 2007 among several countries and regions.

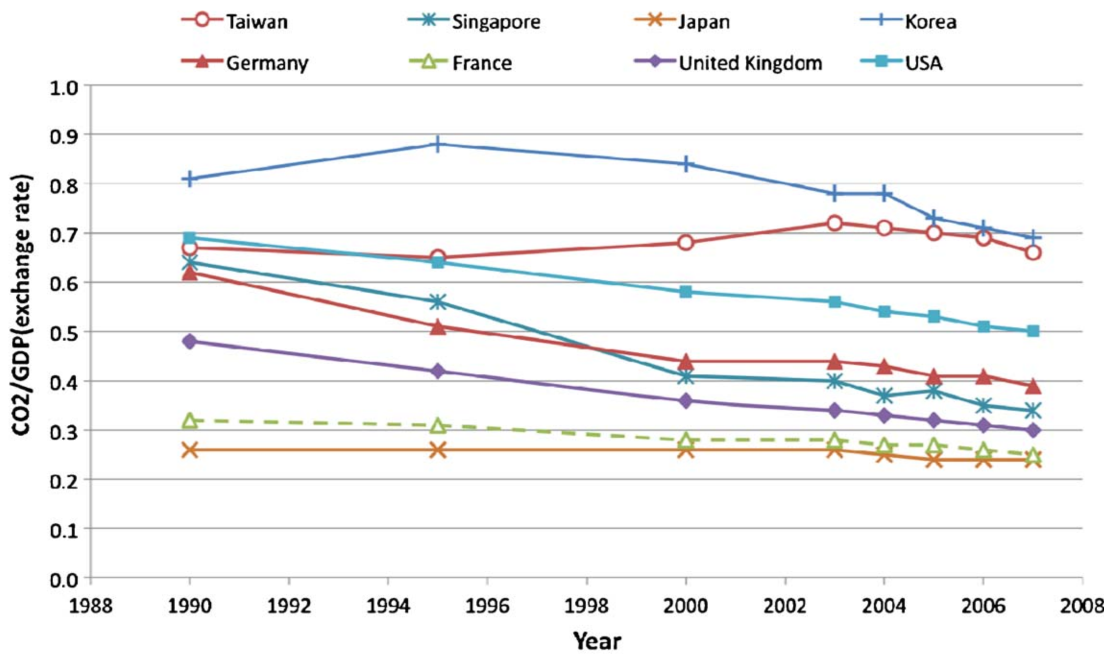


Fig. 8. Comparison of trends of carbon intensity from 1990 to 2007 among several countries.

Since Taiwan's carbon dioxide cutback endeavor can only be carried out locally, the reduction cost is bound to be considerably higher than that of the adjacent countries, which will adversely affect the overall national reduction outcome and international competitiveness.

4. Promotional policies

No single policy/technology measure can provide all of the mitigation potential in any sector [7]. Based on the Frameworks of Sustainable Energy Policy as well as the conclusions of the Third National Energy Conference, the government is providing a comprehensive regulatory framework and relevant mechanisms to achieve the goals of GHG emission reduction, which includes

- Approve the bill of the "Statute for Renewable Energy Development" to develop renewable energy.
- Amend the "Energy Management Act" to improve the energy efficiency of energy-consumption facilities.
- Facilitate the legislation of the "GHG Reduction Act" to build GHG emission reduction capacity and enforce reduction measures.
- Draft and legislate the "Regulations on Energy (Carbon) Tax" to externalize the cost of fossil-fuel energy.

As shown in Table 3, the approaches for mitigation of the climate change in these policy frameworks include developing renewable energy, improving energy efficiency, building capacity of emission reduction, and imposing carbon taxes on fossil fuels. They are described as below.

4.1. Developing renewable energy

The government has passed the bill of "Statute for Renewable Energy Development" in June 2009 [8] that aims to heighten the domestic energy supply, reduce GHG emissions, and establish renewable energy industry. The mechanisms provide incentives for investment in power facilities and promote the use of renewable energy up to a total installed capacity of 6.5–10 GW. As shown in Table 4, the current status (2008) of installed renewable energies in Taiwan is described as follows: 1937.9 MW for hydropower generation; 252 MW for wind power generation; 5.6 MW for solar photovoltaics; 739.3 MW for biomass electrification; the aforementioned data summation is 2934.8 MW, share of which is 6.32% of the nationwide installed capacity in 2008. According to the bill, the share of renewable energy to total generation capacity is projected to increase to 17% by 2030 [8]. It will be near triple current generation capacity from renewable sources. The bill is estimated to spur at least NT$ 30 billion (US$ 937 million) in investment in the first year and create more than 10,000 jobs.

In parallel with the renewable energy development bill, in August 2009, Taiwan government further approved a project for new industrial development, "Takeoff Program for the Green Energy Industry," which will invest NT$ 45 billion (US$ 1.4 billion) in the domestic renewable energy sector in an attempt to help the sector grow nearly eightfold by 2015 thereby increasing industry production value to NT$ 1.158 trillion in 2015 compared to NT$ 160.3 billion in mid-2009. The green energy sector will help Taiwan become a major power in energy technology and production, as well as provide the 110 thousands green jobs [9].

Table 3
Regulatory and policy frameworks in combating climate change in Taiwan.

Bills	Current status	Approaches
Statute for Renewable Energy Development	Approved (June 2009)	Developing renewable energy
Amendment of Energy Management Act	Approved (June 2009)	Improving energy efficiency
Greenhouse Gas Emission Reduction Act	Legislative review	Building capacity of emission reduction
Regulations on Carbon Tax	Legislative review	Imposing carbon taxes on fossil fuels

Table 4
Current status and targets for renewable energy in Taiwan.

Renewables	Year 2008[a] Installed capacity (MW)	Share of total (%)	2030 Installed capacity (MW)
Hydropower	1937.9	4.17	–
Wind power	252[b]	0.54	–
Solar photovoltaics	5.6[c]	0.01	–
Geothermal	0	0	–
Biomass	739.3	1.59	–
Total	2934.8	–	12,934.8
Share of Installed Capacity	–	6.32	17.0%[d]

[a] Total installed capacity: 46,381.6 MW.
[b] Including 6.1 MW non-feed in capacity.
[c] Non-feed-in capacity.
[d] Average annual growth rate by installed capacity was 5.2% from 1998 to 2008, and is assumed to be2.4% from 2009 to 2030. All subsidies providing for new installed capacities.

The Takeoff Program was divided into two parts. The first part focused on solar photovolatics and light-emitting diodes (LEDs), which aims to make Taiwan one of the world's top-three producers of solar cells and the world's largest supplier of LED lights and modules. Taiwan will change all of its 700,000 traffic signals to LEDs and will aim to complete the construction of Asia's largest solar power plant by 2011. LEDs are likely to capture a larger portion of the market for nearly every type of lighting, including displays of electronic devices, streetlights, commercial signage, traffic lights, large public information screens, and LED TVs. The other part of the Takeoff Program promoted wind power generation, biofuels, hydrogen and fuel cells [10–12], energy information and communication technology, and electric vehicles. The government aims to develop Taiwan into a global supplier of wind power generation systems and help the island become a key production base for

Table 5
Measures and targets for improving energy efficiency in various sectors in "Frameworks of Sustainable Energy Policy".

Sectors	Major measures	Targets
Industrial sector	1. Reform the industrial sector towards a high value-added and low energy intensive structure 2. Allocate emission quotas and reduction duty to push the industry towards an energy-conserving and emission-reducing production and sales model 3. Assist small and medium-sized enterprises to improve their emission reduction capacity 4. Establish incentive measures and administrative schemes to encourage the application of clean production technology 5. Promote green energy industry, including energy conserving industries and renewable energy industries, to move towards a clean energy economy	Reduce carbon intensity more than 30% by 2025 (baseline year 2008)
Transportation sector	1. Provide a convenient mass transportation system to reduce the usage of private vehicles 2. Construct an intelligent transportation system to provide instant traffic information and enhance traffic management capacity 3. Build a user-oriented and green-oriented municipal transportation environment	Raise the fuel efficiency standard for private vehicles by 25% in 2015 (baseline year 2008)
Residential and commercial sector	1. Improve urban planning, as well as promote forestation in urban areas to create a low-carbon city 2. Promote low carbon and energy conserving green architecture through energy conserving design of building facades and air-conditioning system 3. Promote energy conserving lighting solutions. Replace conventional lighting devices with high efficiency products	Raise appliance efficiency standards by 10–70% in 2011, and further raise the efficiency standards in 2015
Public sector	1. Integrate carbon neutral concept into policy planning 2. Adopt precaution, alert, and selection principles in carbon administration	Reduce the energy use of governmental agencies and schools by 7% in 2015
General sector	1. Promote public emission reduction movement 2. Promote emission reduction from central government through municipal governments, enterprises, and communities to develop low-carbon consumption habit and build a low carbon and recycling society	Encourage the public to reduce 1 kg of CO_2 footprint per day

electric vehicles [13,14] and fuel cell system assembly in the Asia-Pacific region.

4.2. Improving energy efficiency

In the Frameworks of Sustainable Energy Policy, the government has committed to an energy efficiency improvement of 2% annually for the next few years. So, as compared with the level in 2005, energy intensity will decrease 20% by 2015. Supplemented by further technological breakthroughs and proper administrative measures, energy intensity will decrease 50% by 2025. This target is stricter than Japan's commitment to Asia-Pacific Economic Cooperative (APEC) meetings, which holds a 25%-26% energy efficiency target by 2025 [15]. Table 5 lists the promotion of energy conservation schemes and the corresponding targets in various sectors. Their targets are summarized as below:

1. Industrial sector: reduce the carbon intensity more than 30% by 2025 (baseline year 2008).
2. Transportation sector: raise the fuel efficiency standard for private vehicles by 25% in 2015 (baseline year 2008).
3. Residential and commercial sector: raise appliance efficiency standards by 10–70% in 2011, and further raise the efficiency standards in 2015 to promote high efficiency products.
4. Public sector: reduce the energy use of governmental agencies and schools by 7% in 2015.
5. General sector: encourage the public to reduce 1 kg CO_2 footprint per day.

Actually, the government is currently assisting 200 major energy users (companies and organizations) in implementing energy-saving measures. Through the "Energy Management Act" and the underlying implementing regulations and related measures, companies are encouraged to improve the energy efficiency of their operations and products. Certain mandatory programs have been established for the purpose of energy conservation, including an energy audit regime and energy efficiency standards for certain electrical and electronic products. For example, through the Greenmark program setup by the "Fundamentals for Promoting the Use of the Taiwan Ecolabel," a number of energy-using appliances have been granted Ecolabels. For the electronic products, energy efficiency is one of the most important criteria for granting Green Marks. In addition, the "Statute for Upgrading Industries" provides some economic incentives for the efforts of energy efficiency improvement. Recently (June 2009), several articles of "Energy Management Act" were amended legislatively for further improving the energy efficiency of energy-consumption facilities. In the amendment, explicit regulations on the facilities of lighting, electricity consumption, air conditioning and refrigeration of department stores, office buildings and other public places were added. For example, a maximum fine of NT$100,000 will be issued on overcooling or cool leakages in violation of the energy conservation article. In addition, the energy-consumption standards for vehicles and performance standards for electrical appliances, equipment industry, to achieve the purpose of energy conservation and carbon reduction are regulated.

4.3. Building capacity of emission reduction

In early 2008, the Executive Yuan (Cabinet) of Taiwan passed the draft of "GHG Reduction Act," which is being reviewed by the Legislative Yuan (Congress) for deliberation. Jointly developed by the government and the private sector, the Act establishes a framework to regulate GHG emissions based on emission efficiencies and new-source emissions, as well as penalties for non-compliance. In addition to serving as the legal basis for developing and implementing domestic GHG emission reduction measures, the Act also demonstrates to the international community Taiwan's willingness to participate in global actions to reduce GHG emissions and to fulfill its responsibilities as a member of the international community. If the legislative process proceeds on schedule, Taiwan will likely become the first country with GHG reduction legislation among Asian countries. As shown in Table 6, the key elements of the Act (6 chapters with 30 articles) are outlined below:

- GHG Emission Permits: Designated emission sources must conduct annual emission inventory and verification, and then register on the platform of Environmental Protection Administration (EPA). Existing, new or modified emission sources above certain level must apply for an emission permit from the EPA, and operate, monitor, record and report emissions in accordance with the permit conditions. The EPA will set related management regulations.
- GHG emission standards: Designated emission sources to comply with GHG emission standards (Benchmark, e.g. GHG emission per metric ton of steel production) based on established emission intensity for new/existing emission sources, installation under various sectors, products, etc. The standards would be set by the EPA in consultation with the central industry competent authorities, such as the Bureau of Energy and the Industrial Development Bureau.
- Cap-and-trade schemes: In the final stage of the GHG management, Taiwan will set a national emissions target and implement a domestic cap-and-trade system, as a part of our economic and financial policy instruments to reduce GHG emissions. The

Table 6
Legislative frameworks of GHG reduction in Taiwan.

Items	Measures
General (Articles 1–5)	Objectives Targets Terms Competent authorities
Competent Authorities (Articles 6–11)	Form interagency GHG reduction task force Develop national GHG reduction plan Establish GHG inventory, assist the industries with inventory, registration and voluntary reduction Review and modification of energy, industry and environmental policies Local competent authorities
Reduction Measures (Articles 12–19)	Inventory, registration and verification of designed sources Establish GHG emission standards Conditions for implementing cap-and-trade schemes Regulation of new sources or expansion of existing sources Checking
Education and Promotion (Articles 20–22)	Education and public participation Green procurement Responsibilities of energy supplier Responsibilities of citizens
Penalties (Articles 23–30)	Penalties for no inventory and reporting Penalties for false reporting Penalties for non-compliance with cap or emission standards In effect one year promulgation

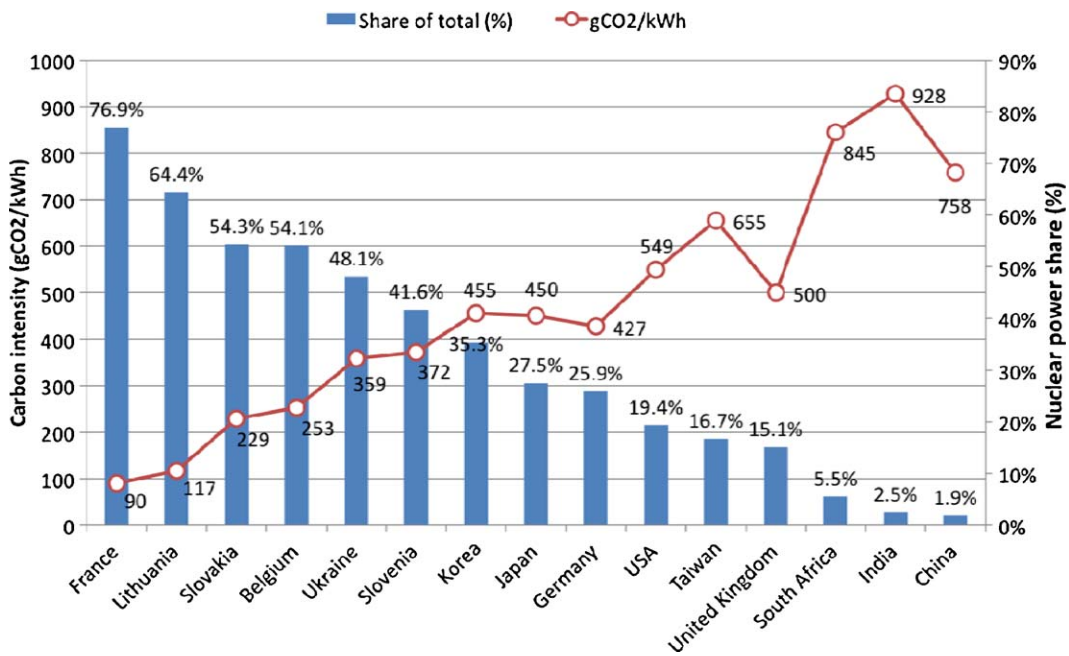


Fig. 9. Relation between carbon intensity of electricity and share of nuclear power in generation capacity.

timing and stringency of the target setting would depend on the progress of international negotiations on climate change, as stipulated in the Bill.

4.4. Imposing carbon taxes on fossil fuels

Literature has identified taxes as an efficient way of internalizing costs of GHG emissions [7]. Levying the energy (carbon) tax was a politics of President Ma Yin-Jeou in 2008 campaign. Thereafter, the Frameworks of Sustainable Energy Policy includes "legislating the Regulations on Energy (carbon) Tax to reflect the external cost of energy consumption" into its vital regulatory frameworks. The energy-tax policy is currently on the drawing board of the Executive Yuan (Cabinet). There will be many complementary measures and amendments to existing laws before the implementation of energy (carbon) tax policy.

According to the governmental schedule, first, the energy tax will be the integration of the existing fuel tax such as commodity tax, fuel use tax, and petroleum fund. That is it will consolidate the fees that everyone already pays into a single energy tax. Therefore, the government does not raised taxes at all in this stage. In the next stage, carbon (new) taxes will be imposed on fossil fuels based on the carbon price.[2] In the governmental design, the carbon tax should be revenue-neutral, i.e., no tax increase. The impacts of added costs will be softened by paying back the tax revenues (dividends) or reducing other taxes (tax-shifting), such as raising the minimum imputation credit for income tax computation, and implementing energy welfare programs for guaranteeing the basic right of the people to a minimum energy supply. In addition, the timing for imposing carbon taxes would depend on international trends, especially the actions of neighboring nations such as China, Japan, South Korea and Southeast Asian countries. That is the government will consider the domestic industrial development and competitiveness, and especially the approach of the above rivals in their deliberations over the carbon tax. That way will soften the measure's impact on industry and help maintain its competitiveness. Actually, none of the above nations have levied carbon so far. Thus, the carbon-tax policy would not be implemented before 2011 based on the governmental estimation.

4.5. Increasing carbon-free energy mix

In addition to the regulatory frameworks list in Table 3, the Frameworks of Sustainable Energy Policy reconsiders nuclear power as a carbon-free energy option, which will be the major approach to increase the share of low-carbon energy from the current 40% to 55% in 2025 (one of targets of the Policy) in electricity generation systems. According to the IPCC Fourth Assessment Report [7], the nuclear power belongs to key mitigation technologies and practices currently commercially available. Fig. 9 concluded the relation between carbon intensity of generation (per kWh emission) and share of the nuclear power in its power capacity in several countries. It is seen from this figure that the higher share of nuclear power in the generation capacity is, the lower is the carbon intensity of generation. Notable drops of the curve of carbon intensity of generation for German and Unite Kingdom are attributed to the additional benefits of high shares of renewable energy and gas-fired power, respectively [16].

In Taiwan, since concerns about safety, weapons proliferation and waste remain as constraints for nuclear power, the development of nuclear power is quite wavering. Support for nuclear power is largely split between the two major political parties, i.e., KMT and the DPP. The DPP came to power advocating a nuclear-free policy in the years of 2000–2008. Its rule has shown little sign of altering its position, even though nuclear plants would support the goal to reduce GHG emissions [5]. Instead, it added more privately run coal-fired plants. The situation is significantly altered after the KMT win back power in 2008.

Actually, nuclear power has been an important part of the electricity supply in Taiwan for decades. Currently, there is 5144 MW of nuclear power capacity by means of 3 active plants and 6 reactors, as shown in Table 7. They comprises 11% installed capacity, and provides almost 20% of base load and 16.8% overall in 2007. This makes Taiwan the 15th largest user of nuclear power in the world. There are two additional reactors (#4 plant) under construction equipped with GE latest ABWR technology in

[2] The public and private sectors has discussed the carbon price for a long time but did not reach a consensus about the carbon price yet. The proposed carbon price varied from NT$750 to NT$2000 per metric ton.

Table 7
Status of nuclear power in Taiwan.

Plant	Unit	Type	Capacity/MW	Start up[a]	Licensed to
#1	Chinshan 1	BWR	636	1978	2017
	Chinshan 2	BWR	636	1979	2018
#2	Kuosheng 1	BWR	985	1981	2010
	Kuosheng 2	BWR	985	1983	2012
#3	Maanshan 1	PWR	951	1984	2013
	Maanshan 2	PWR	951	1985	2014
#4	Lungmen 1	ABWR	1350	2010	2039
	Lungmen 2	ABWR	1350	2011	2040
	Total (8)			7844 MW	

BWR: Boiling Water Reactor; PWR: Pressurized Water Reactor; ABWR: Advanced Boiling Water Reactor.
[a] Dates are for start of commercial operation.

Lungmen near Taipei. They were scheduled for commercial operation in mid 2006 and mid 2007, but current delays and estimates suggest 2011 and 2012 due to a temporary suspension of the project by the DPP in 2000 after winning power. Under the above constraint conditions and supply-side control, the carbon intensity can be reduced from 0.655 kg CO_2/kWh to 0.53 kg/kWh when the fourth nuclear plants begins operation [17].

Owing to the growing global trend of re-evaluating nuclear power, the government is planning to formally reconsider nuclear power. The first step is to extend the licenses of the existing reactors. In 2007, the Chinshan plant had undergone a safety evaluation and was safe to run for a further 20 years following planned license expiry in 2017. The next step is to consider the possibility of increases the share of the nuclear power in its power structure. It is uncertain about building the fifth nuclear plant. Alternatively, each of three operational nuclear plants and the fourth plant, have space to add additional units. According to the original design, nuclear plants #1 and #2 have the room for additional two units each, while #3 and #4 could add four more each, increasing the total number of nuclear power units on the island to 20 from 8. If all those units were built with an average of 1000 MW each, they could increase the island's total installed capacity by up to a third, which is comparable to those of the neighboring countries of Japan and South Korea. It is estimated that the carbon intensity of generation would be reduced to 0.4 kg CO_2/kWh after finishing the above installation.

5. Conclusions

The outcome of GHG emission reduction and the corresponding policy progress of Taiwan has been evaluated in the present review. Due to the unique political situation of Taiwan, the tools of GHG emission reduction are limited. It is unable to take part in the international mechanisms such as Joint Implementation, Clean Development Mechanism and Emission Trade. Even though, Taiwan is ready to participate in global actions to reduce GHG emissions and to fulfill its responsibilities as a member of the international community. The government has set an aggressive target that cuts GHG emission in half of 2000 level by 2050. To achieve this target,

1. Taiwan will accelerate legislative review of the drafts for "GHG Reduction Act" to give legal basis for our GHG emission reduction endeavor and attain the expected results of the reduction measures.
2. Taiwan will step up the GHG inventory scheme in conjunction with the implementation of validation system by the government, and publish national report of GHG at an opportune time.
3. Taiwan will implement its GHG control strategies and action plans, including improving efficiency of energy use, promoting energy conservation, developing renewable energy, imposing carbon tax on fossil fuels, and increasing the share of carbon-free fuel in its generation structure.
4. Taiwan will watch closely the development of post-Kyoto and gather information on the current status of emission trading in the international community to avoid any international sanction and ensure sustained development.

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References

[1] Social Indicators 2008, Directorate General of Budget, Accounting and Statistics, Executive Yuan, Taiwan. http://eng.dgbas.gov.tw/.
[2] Energy Statistics Handbook 2008, Bureau of Energy, Ministry of Economic, Taiwan; 2008.
[3] 2005 National Energy Conference, Bureau of Energy, Ministry of Economic Affairs. http://www.moeaboe.gov.tw/hot/EnergyMeeting/defalult.htm.
[4] Huang WM, Lee GWM. Feasibility analysis of GHG reduction target: lessons from Taiwan's energy policy. Renewable and Sustainable Energy Reviews 2009;13:2621–8.
[5] Hsu SH. Advocacy coalitions and policy change on nuclear power utilization in Taiwan. The Social Science Journal 2005;42:215–29.
[6] CO_2 Emissions from Fuel Combustion-2009 edition, International Energy Agency (ISBN 978-92-64-06102-6)
[7] Climate Change 2007: Synthesis Report, An Assessment of the Intergovernmental Panel on Climate Change; 2007.
[8] Hwang JJ. Promotional policy for renewable energy development in Taiwan. Renewable and Sustainable Energy Reviews 2010;14:1079–87.
[9] Taiwan targets renewables with an investment package of almost €1 billion, Renewable Energy Magazine, Latest news, 2009. http://www.renewableenergymagazine.com/.
[10] Chang WR, Hwang JJ, Su A, Weng FB. Effect of clamping pressure on the performance of PEM fuel cells. J Power Sources 2007;166:149–54.
[11] Hwang JJ. Thermal-electrochemical modeling of a PEM fuel cell. J Electrochem Soci 2006;153:A216–24.
[12] Hwang JJ, Chao CH, Chang CL, Ho WY, Wang DY. Modeling of two-phase temperatures in a two-layer porous cathode of polymer electrolyte fuel cells. Int J Hydrogen Energy 2007;32:405–14.
[13] Hwang JJ, Wang DY, Shih NC. Development of a lightweight fuel cell vehicle. J Power Sources 2005;141:108–15.
[14] Hwang JJ, Chang WR, Su A. Development of a small vehicular PEM fuel cell system. Int J Hydrogen Energy 2008;33:3801–7.
[15] The 15th Asia-Pacific Economic Cooperation (APEC) Economic Leaders' Meeting, Sydney, Australia, 9 September 2007.
[16] Energy Statistics of OECD Countries-2009 Edition, International Energy Agency, ISBN 978-92-64r-r06117-0.
[17] Taiwan Power Company Sustainability Report (in Chinese). Taiwan Power Company; 2009.